Generation of GeV Photon Energy at European X-Ray Free Electron Laser

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How to get GeV-range photons?

- Bremsstrahlung radiation

  + Hight flux

  - Too wide spectrum

- FEL

  + in theory possible

  - Not today

- Compton Back Scattering

  + the most efficient energy amplifier

  + Tunable spectrum

  + Controlling polarization

  - low cross-section ~10^{-25} cm

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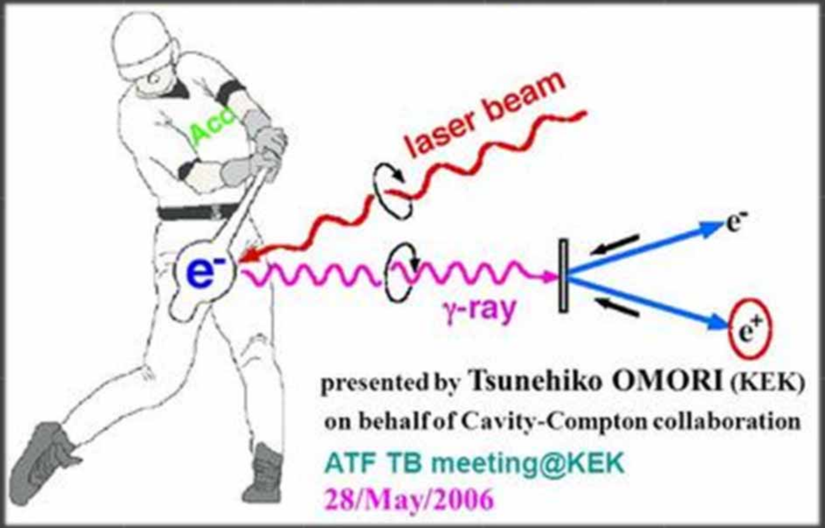
What is Compton Back Scattering?



presented by **Tsunehiko OMORI** (KEK)
on behalf of Cavity-Compton collaboration
ATF TB meeting@KEK
28/May/2006

$$\nu = \frac{(1+\underline{e}_k\cdot\underline{\beta})}{(1-\underline{n}\cdot\underline{\beta})+\frac{h\nu_L}{mc^2\gamma}(1-\underline{e}_k\cdot\underline{n})}\nu_L \approx 4\gamma^2\nu_L$$

1-βcosθ

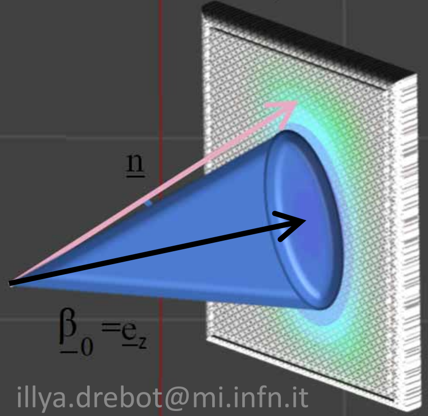
Frequency-angle correlation

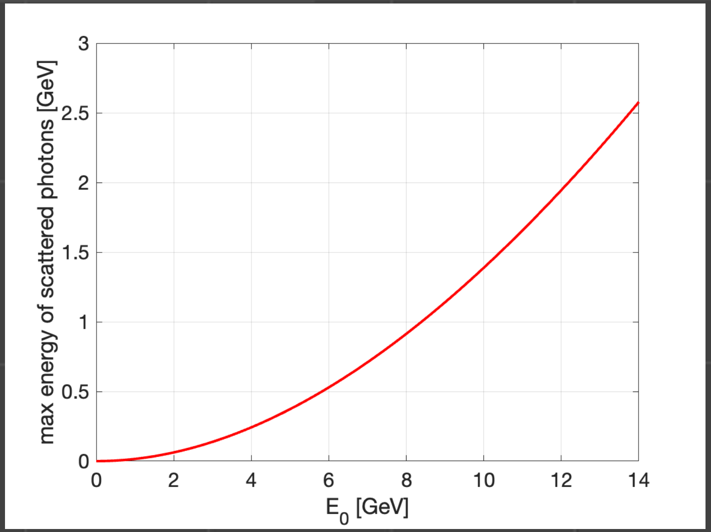
Total acceptance

$$\Psi_{max}=\gamma\theta_{max}=1$$

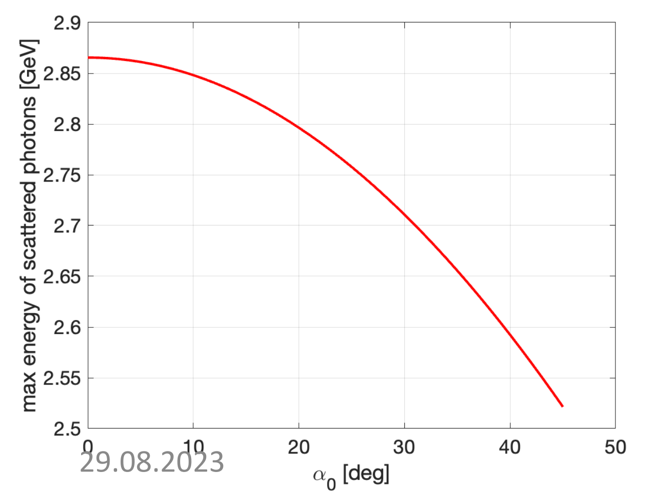
$$\theta_{max}=1/\gamma$$

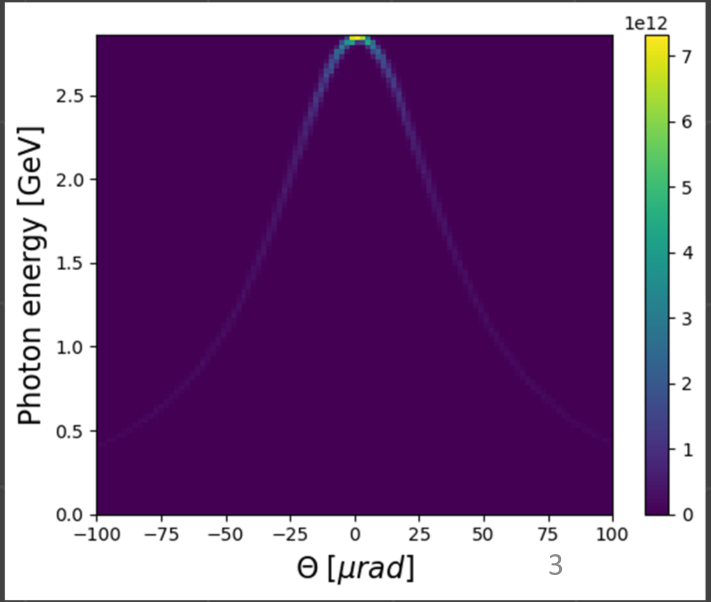
E=14 GeV-> **γ** = 2.7e+04
Θmax=37 μrad





$$\varepsilon_{\gamma m}=\frac{4\gamma^2\varepsilon_L\cos^2\frac{\alpha_0}{2}}{4\gamma\frac{\varepsilon_L}{mc^2}\cos^2\frac{\alpha_0}{2}+1}\approx 4\gamma^2\varepsilon_L cos^2\frac{\alpha_0}{2}$$





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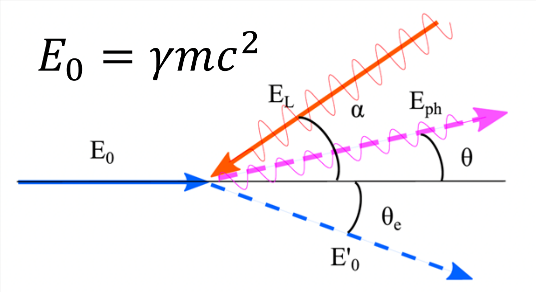
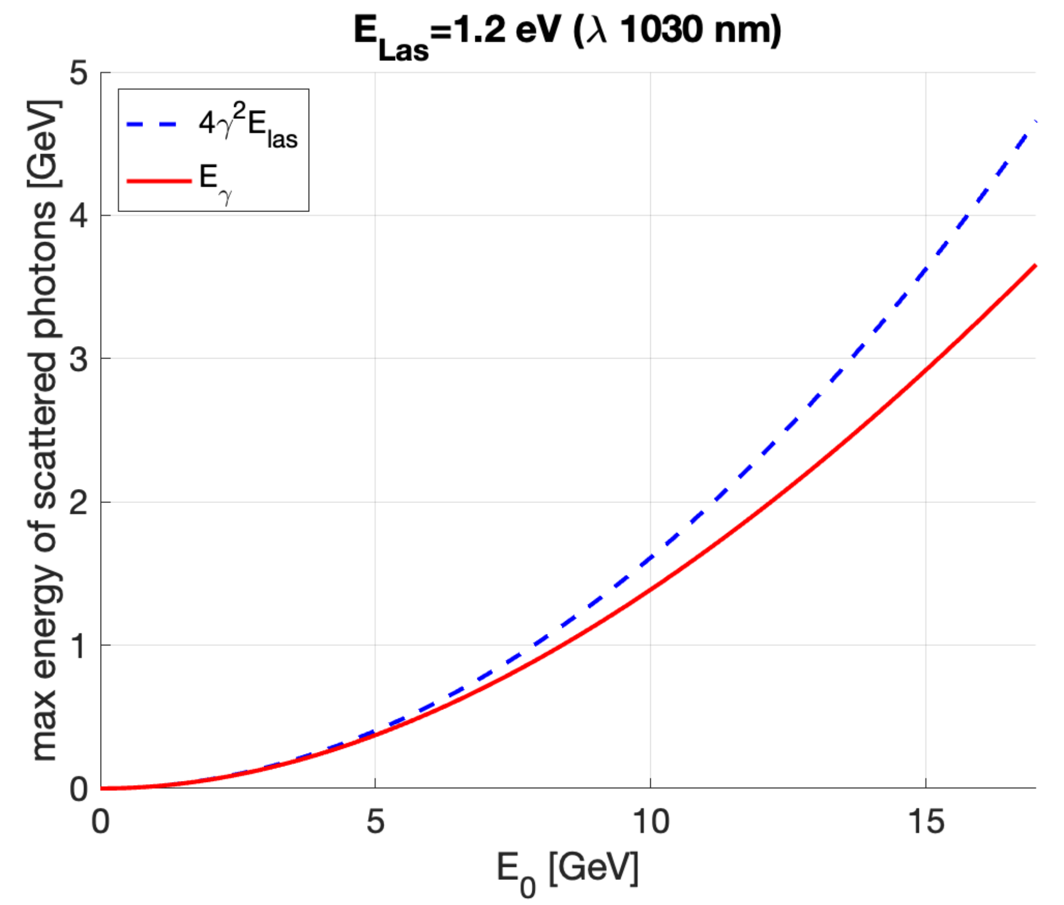


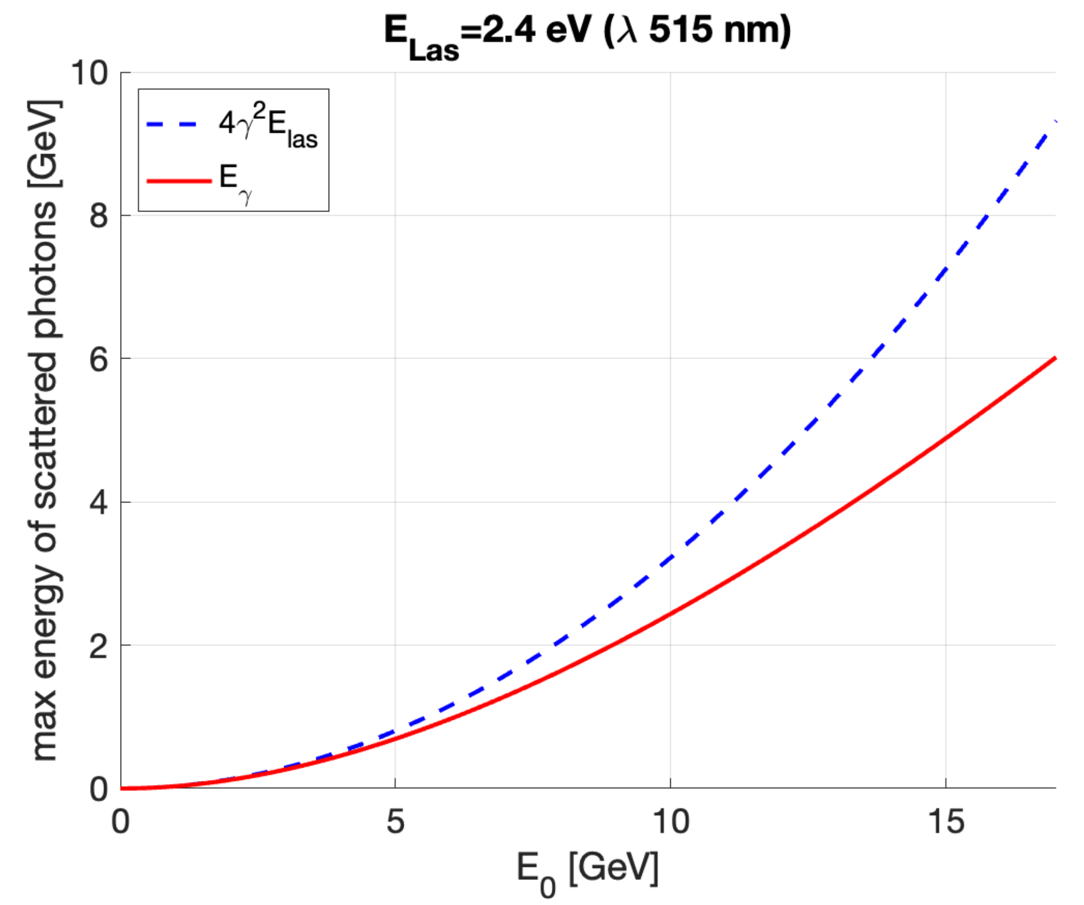
$$E_0 = \gamma m c^2$$

$$E_{ph} = \frac{4\gamma^2 E_l}{1 + X + \gamma^2 \vartheta^2}$$

$$X \equiv \frac{4\gamma E_l}{mc^2}$$



E_{Las}=1.2 eV (λ 1030 nm)



E_{Las}=2.4 eV (λ 515 nm)

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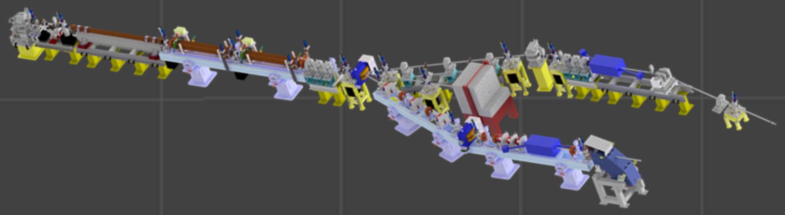
3 possible

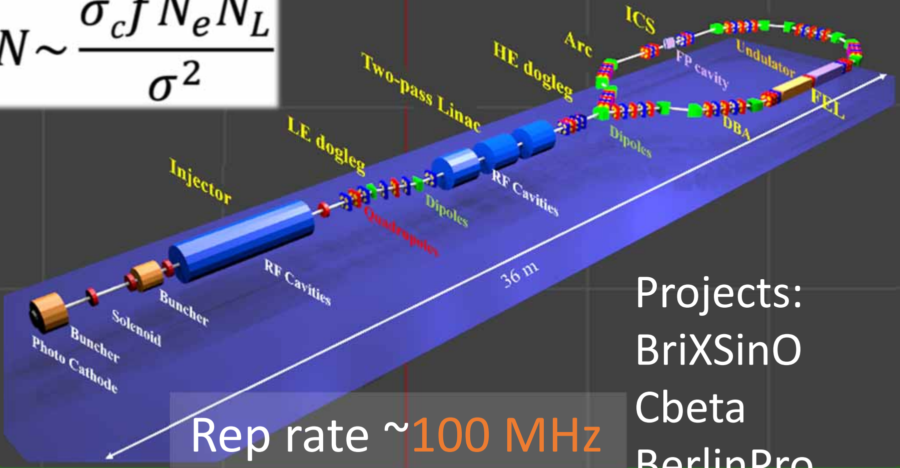
Based on linear accelerators



Projects:
STAR2
SMART*LIGHT

Based on ERL

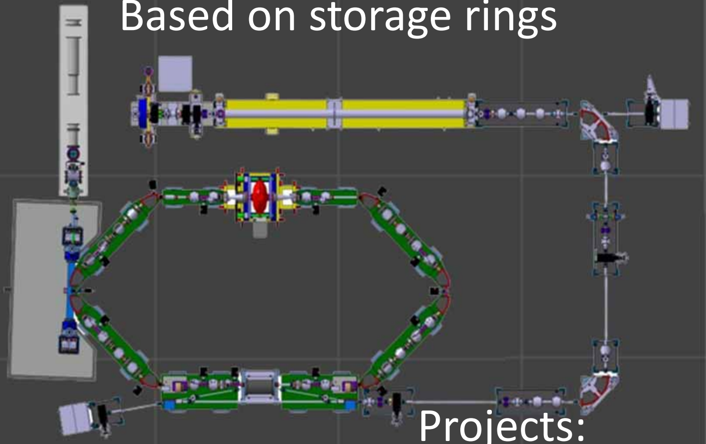
$$N \sim \frac{\sigma_c f N_e N_L}{\sigma^2}$$



Rep rate ~100 MHz

Projects:
BriXSinO
Cbeta
BerlinPro

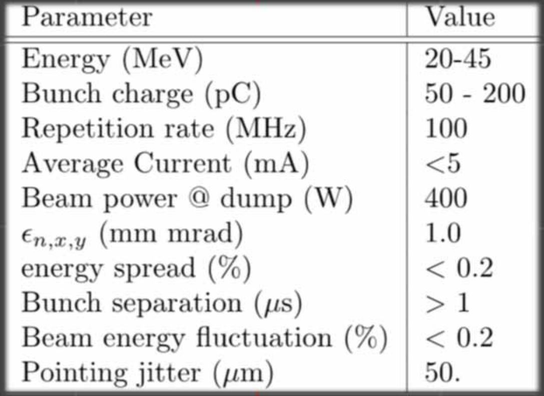
Based on storage rings



Projects:
MuCLS
HIGS
ThomX
NESTOR

Advantage:
- Small emittance 2-3 mmrad
- Possibility to focus beam at 5-10 µm
- Hight flexibility in tuning

Disadvantage
- Low repetition rate 100 Hz



Parameter	Value
Energy (MeV)	20-45
Bunch charge (pC)	50 - 200
Repetition rate (MHz)	100
Average Current (mA)	<5
Beam power @ dump (W)	400
$\epsilon_{n,x,y}$ (mm mrad)	1.0
energy spread (%)	< 0.2
Bunch separation (μs)	> 1
Beam energy fluctuation (%)	< 0.2
Pointing jitter (μm)	50.

Advantage:
- Hight repetition rate 17.8 MHz

Disadvantage
- Bigger emittance 60 mmrad
- Bigger transvers size at IP ~70 µm

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Gamma photons at XFel

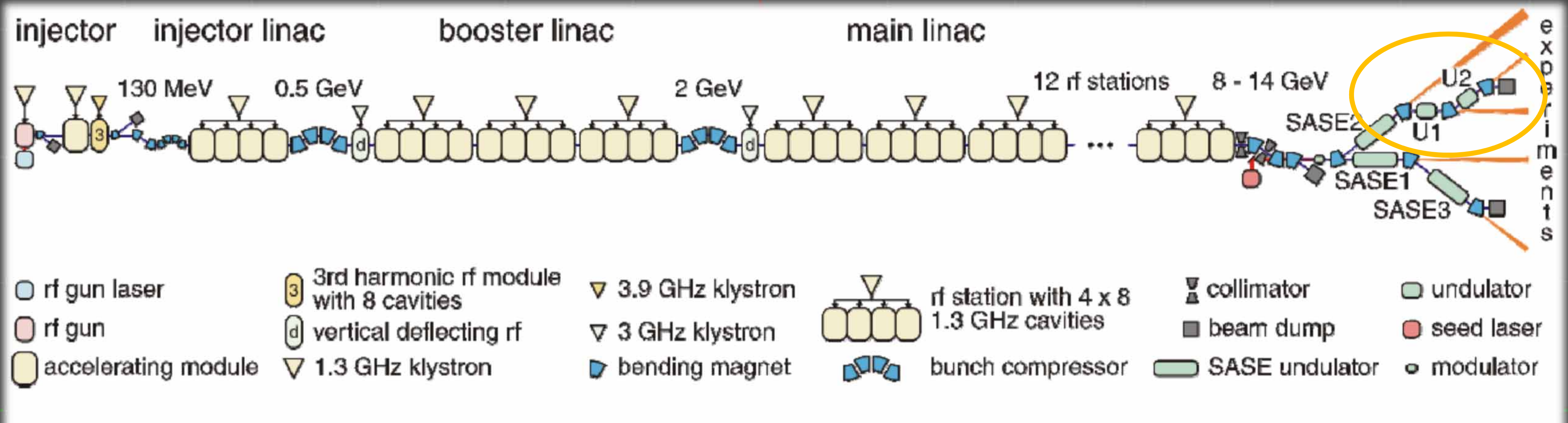
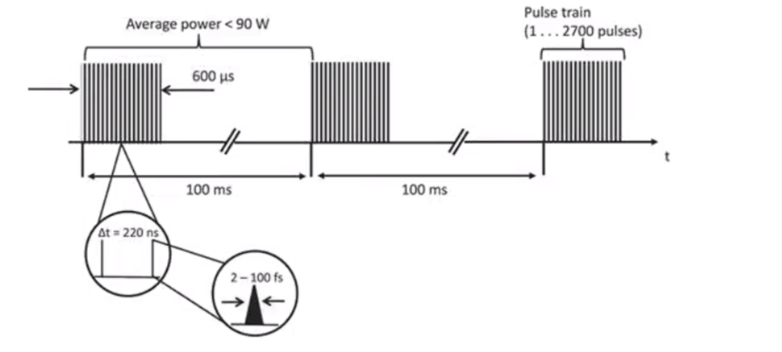
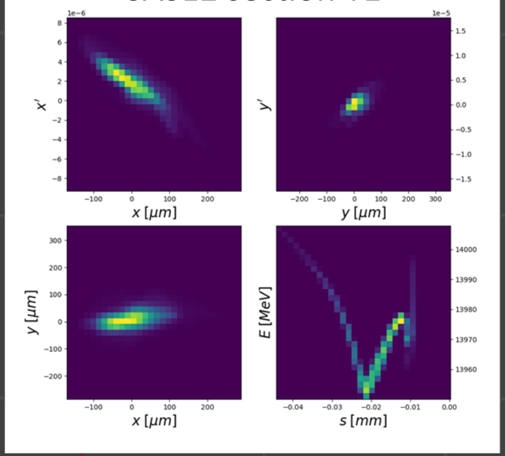


Figure 1: Schematic layout of the European XFEL complex, the third harmonic system is at the injector stage.



The pulse structure of the EuXFEL. The pulse trains arrive at a 10 Hz, and the pulses within each train are separated by 220 ns (4.5 MHz intra-bunch-train repetition rate).[1]

SASE2 section T1



Bunch charge = 247 [pc]

E_e= 13.9 [GeV]

δ_e = 7.45012e-04

$\boldsymbol{\gamma}$ = 2.7e+04

ε_{xn} = 1.17887e-06 [m rad]

ε_{yn} = 9.69882e-07 [m rad]

σ_x = 53.6 [μm]

σ_y = 29.5 [μm]

σ_z = 6 [μm]

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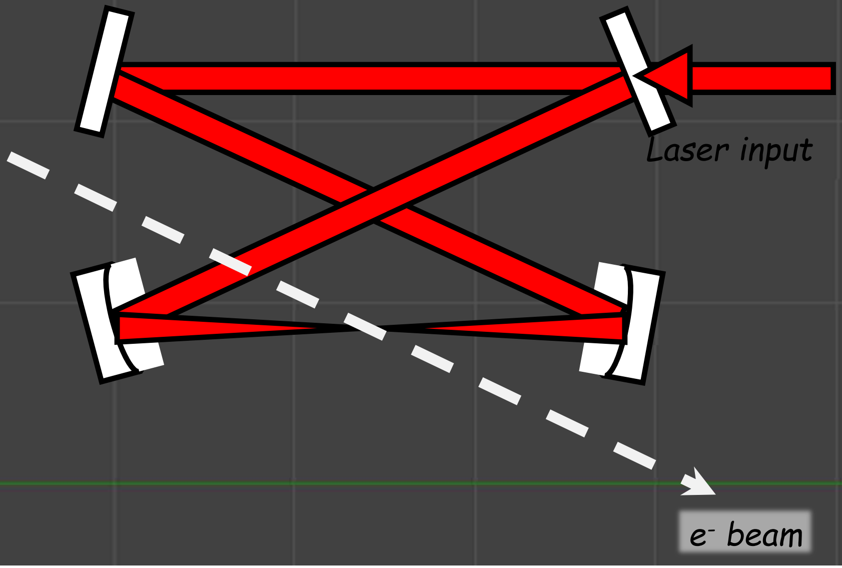
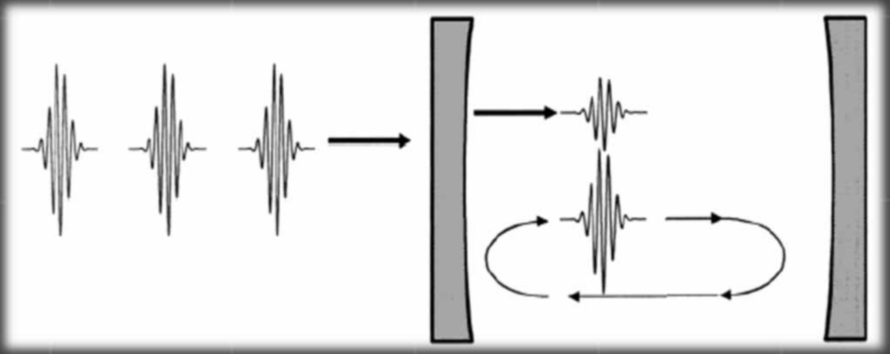
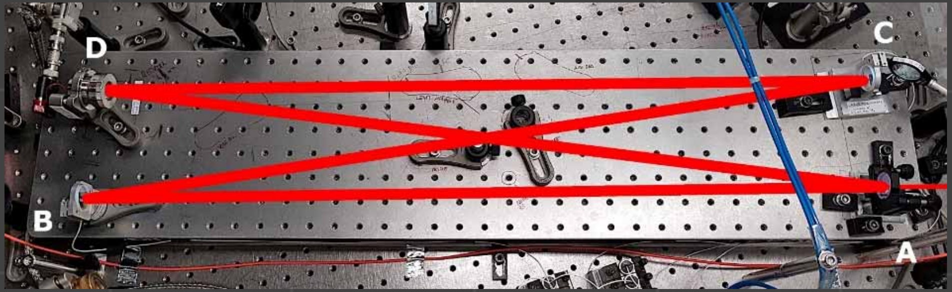
Laser & Fabry-Perot cavity





Laser and Fabry-Perot cavity accumulate photons.
It give us possibility to collide photons with pulse energy of 3 mJ

Laser and FP cavity	
Laser wavelength	1030 nm E_{las}=1.2 eV
Laser and FP cavity Frep	96 MHz
Pulse energy	2.7 mJ
FP waist	40 μm
Laser pulse length	1 ps



BriXSinO Fabry-Perot cavity

BriXSinO TDR: https://marix.mi.infn.it/brixsino-docs/

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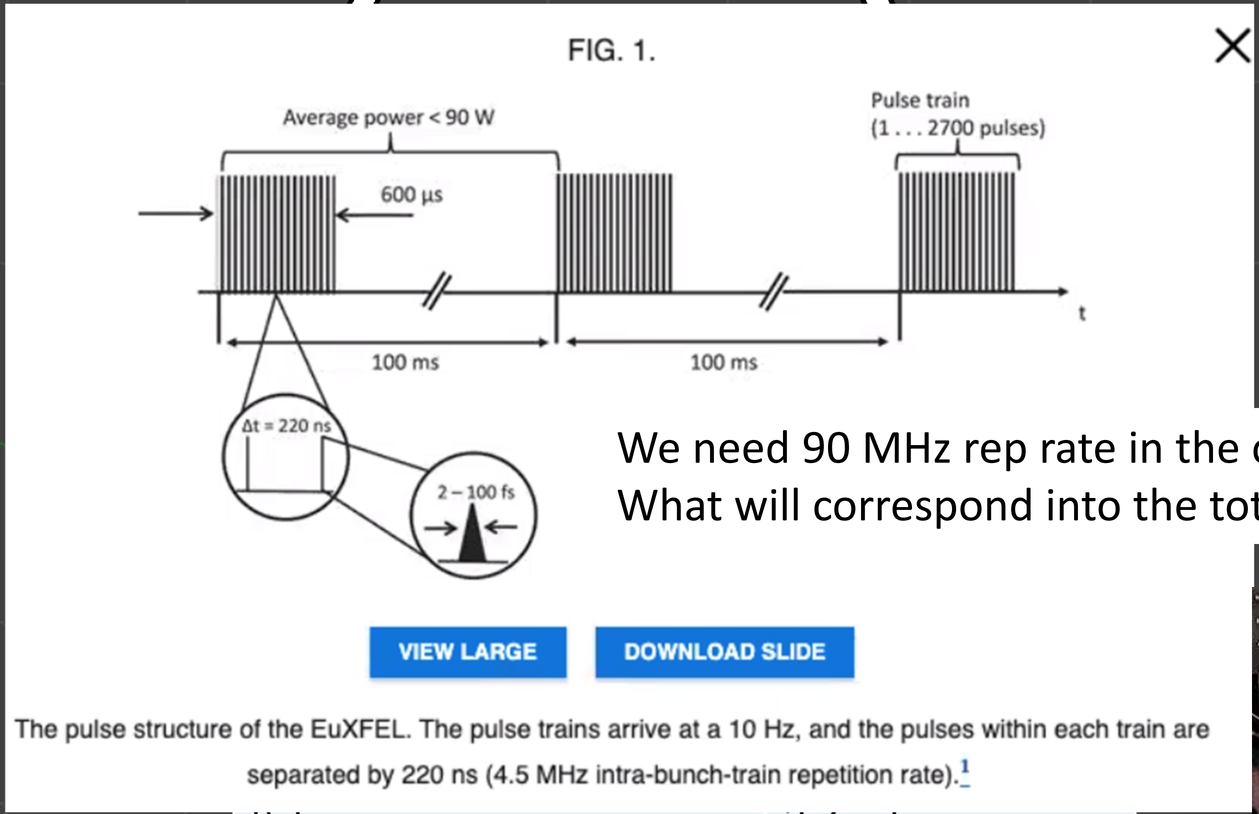
Laser & Fabry-Perot cavity



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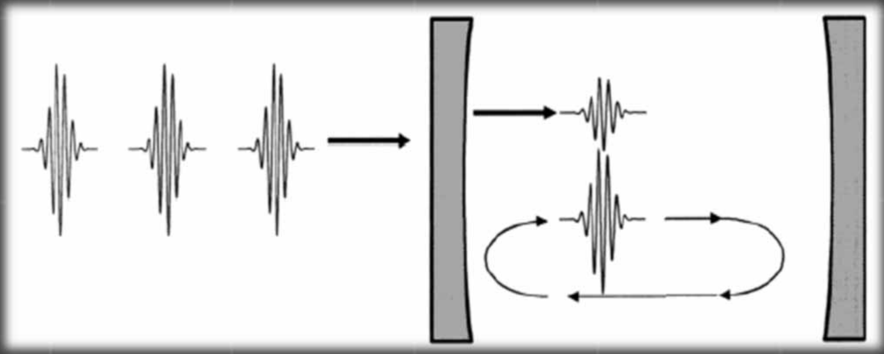
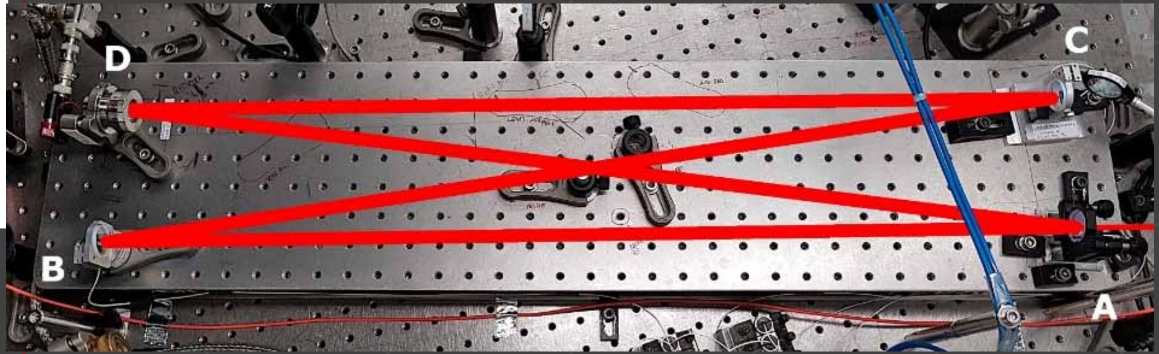


Laser and Fabry-Perot cavity accumulate photons.

We need 90 MHz rep rate in the cavity like this each 20th laser will hit the e bunch inside train
What will correspond into the total rep rate 27 kHz



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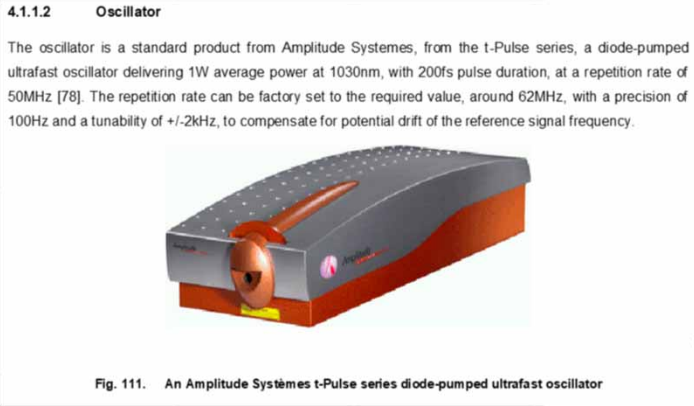
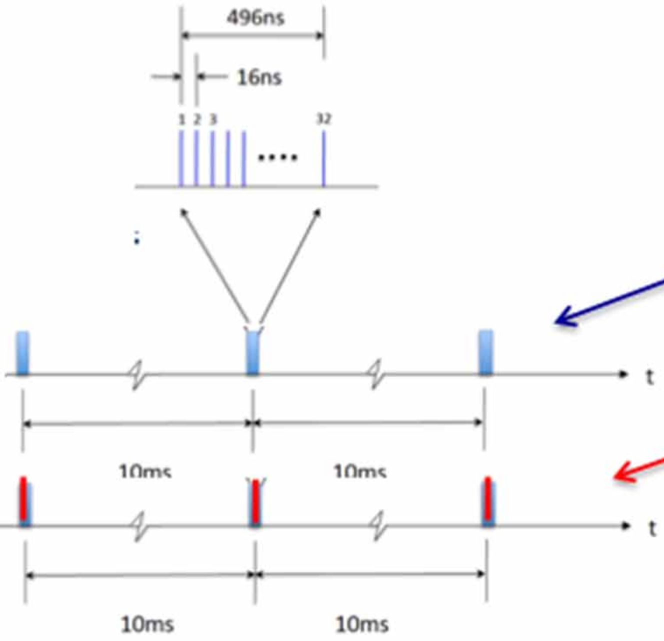
Laser Recirculation at IP



4.1.1.2 Oscillator

The oscillator is a standard product from Amplitude Systemes, from the t-Pulse series, a diode-pumped ultrafast oscillator delivering 1W average power at 1030nm, with 200fs pulse duration, at a repetition rate of 50MHz [78]. The repetition rate can be factory set to the required value, around 62MHz, with a precision of 100Hz and a tunability of +/-2kHz, to compensate for potential drift of the reference signal frequency.

Fig. 111. An Amplitude Systèmes t-Pulse series diode-pumped ultrafast oscillator

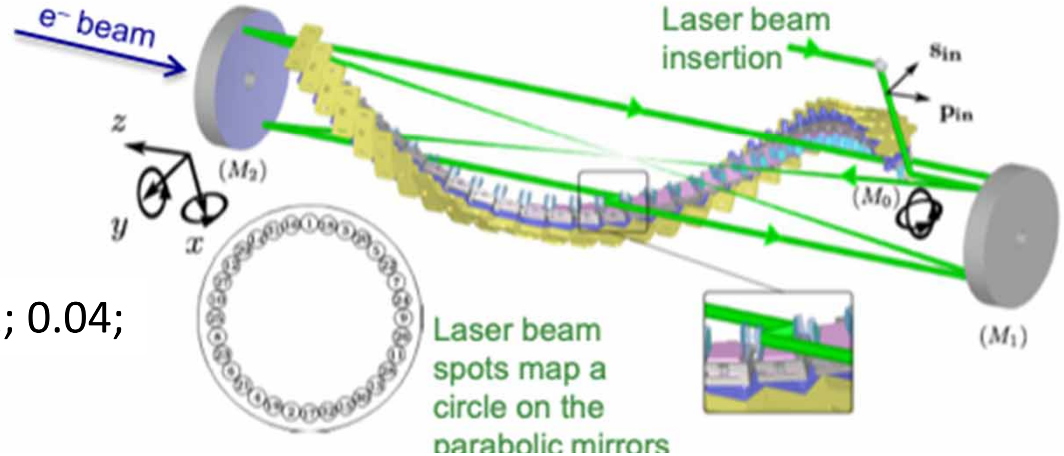


Designed by

Electrons rep. rate –macropulses 100 Hz
32 micropulses @ 16 ns

Laser rep. rate – 100 Hz → ***laser recirculation***

'Dragon–shaped' Laser Recirculation



Laser and FP cavity	
Laser wavelength	515 nm E_{las}=2.4 eV
Laser and FP cavity Frep	100 Hz
Pulse energy	0.2J 0.4J
FP waist	40 μm
Laser pulse length	1 ps

$a_0 = 4.3\left(\frac{\lambda}{w_0}\right)\sqrt{\frac{U[\mathrm{J}]}{\sigma_t[\mathrm{ps}]}}$ =0.02; 0.04;

ELI_NP TDR: https://arxiv.org/abs/1407.3669

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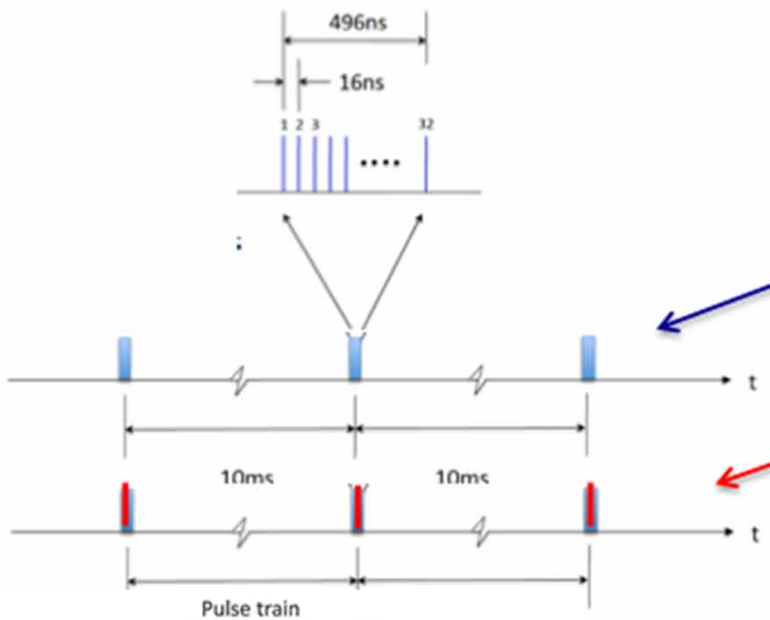
Designed by



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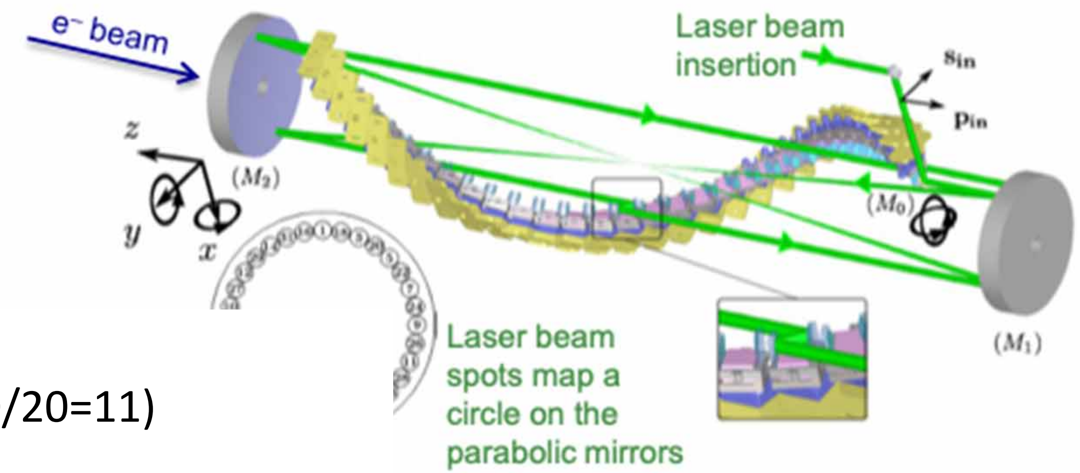
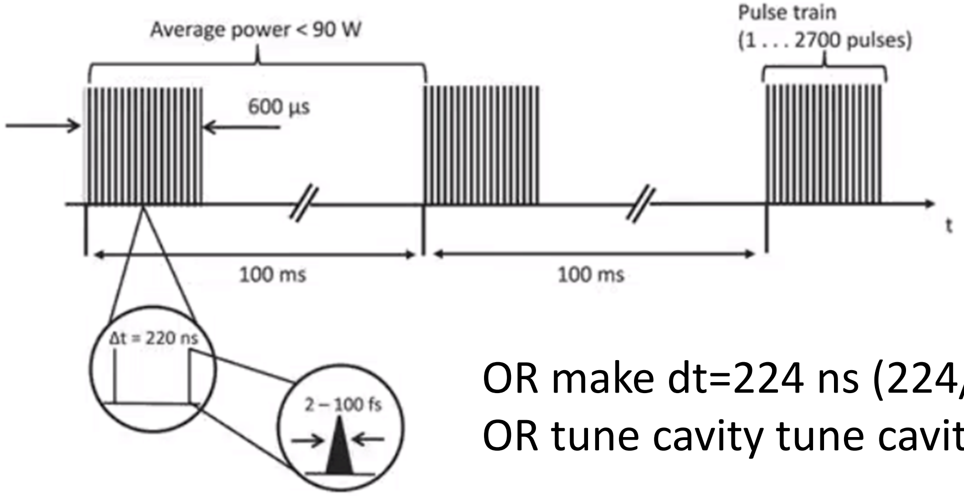
'*Dragon–shaped*' Laser Recirculation





The pulse structure of the EuXFEL. The pulse trains

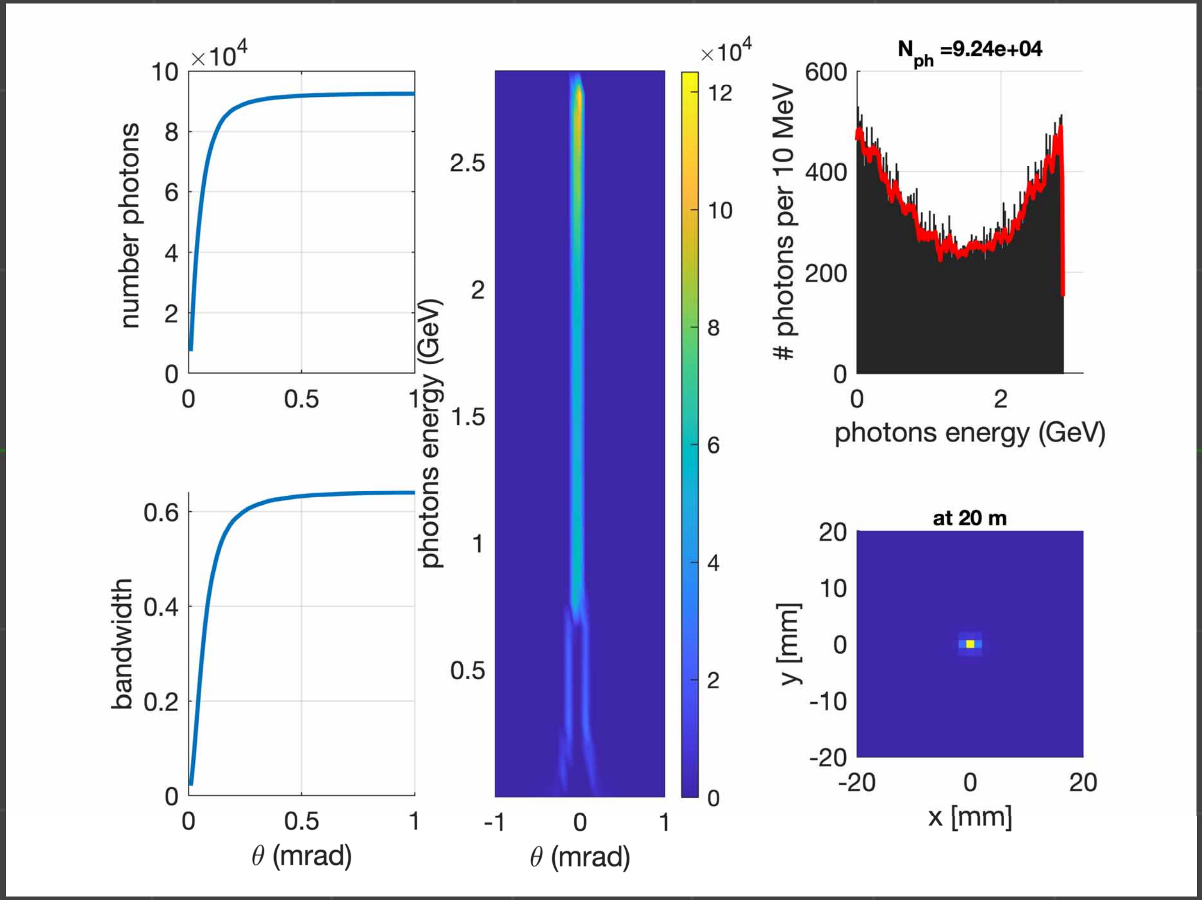
separated by 220 ns (4.5 MHz intra-bunch-train repetition rate).[1]

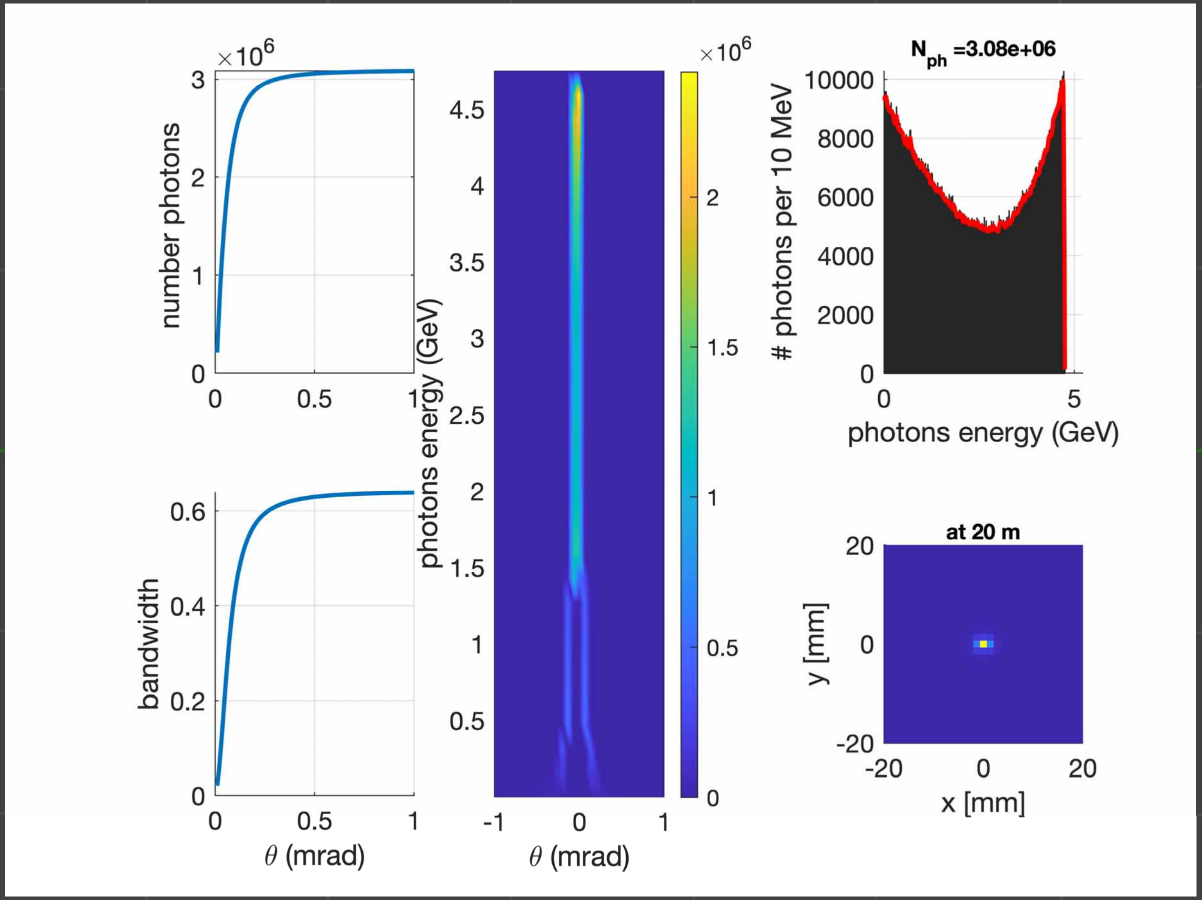
OR make dt=224 ns (224/16=14)
OR tune cavity tune cavity dt=20 ns (220/20=11)

Like this each 10 Hz one laser train will hit 32 e bunches
Total rep rate 320 Hz

E_{las}=1.2 eV (1030 nm). PulseE=2.7 mJ

E_{las}=2.4 eV (515 nm). PulseE=0.2 J





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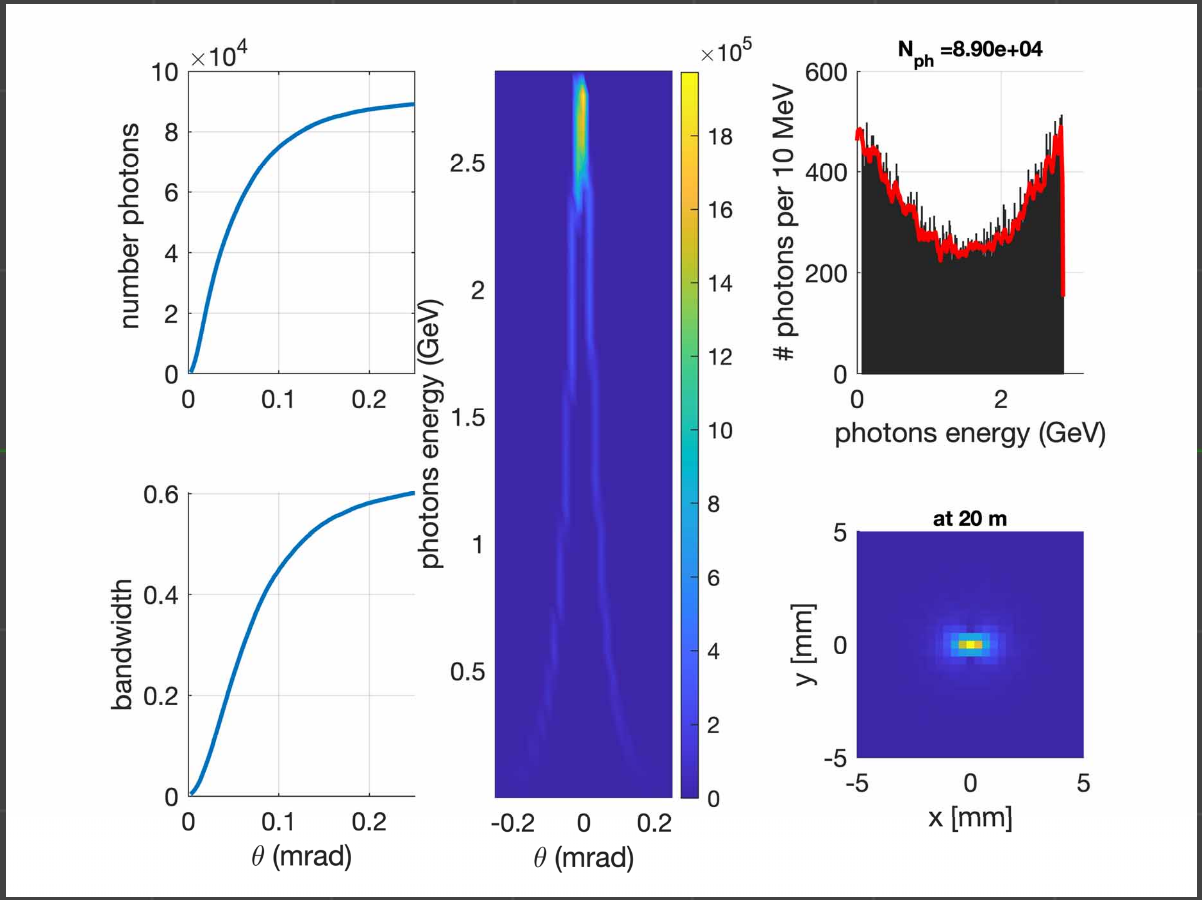
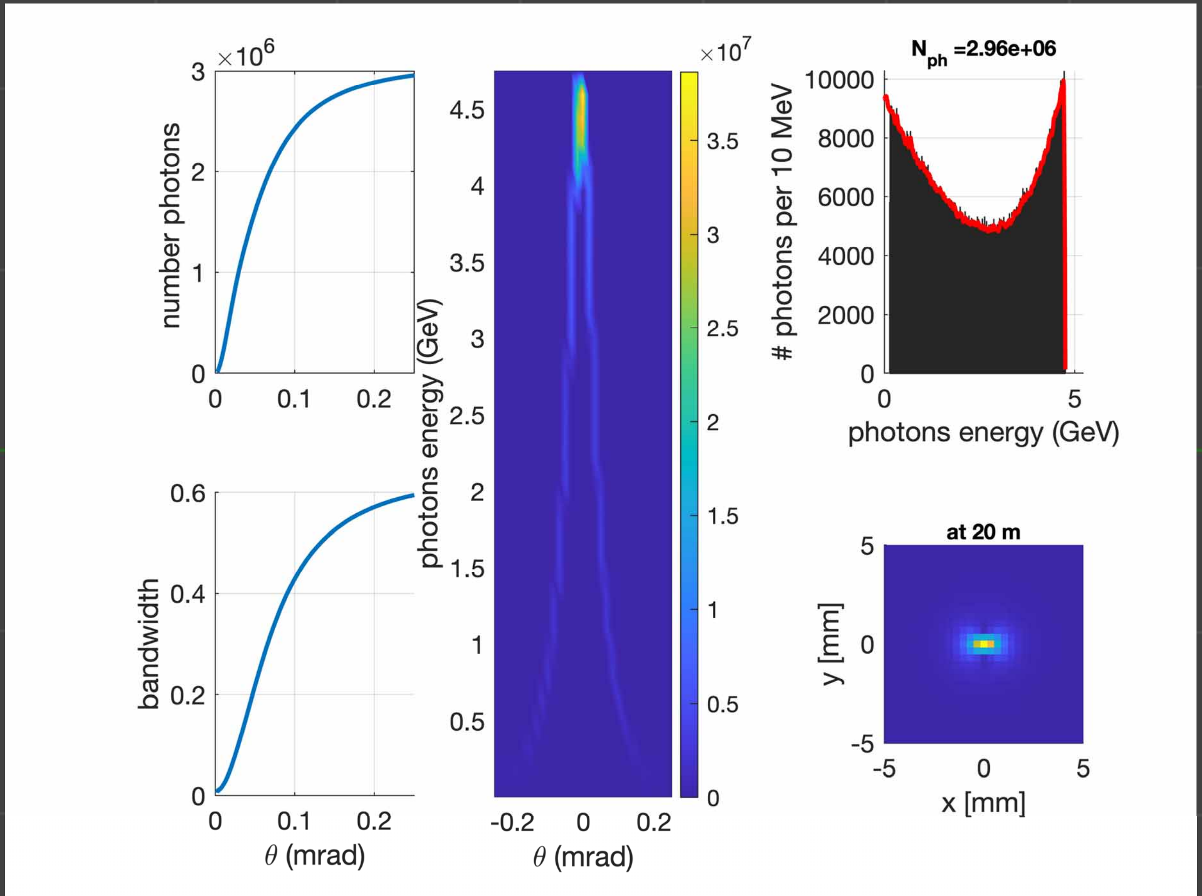


E_{las}=2.4 eV (515 nm). PulseE=0.2 J



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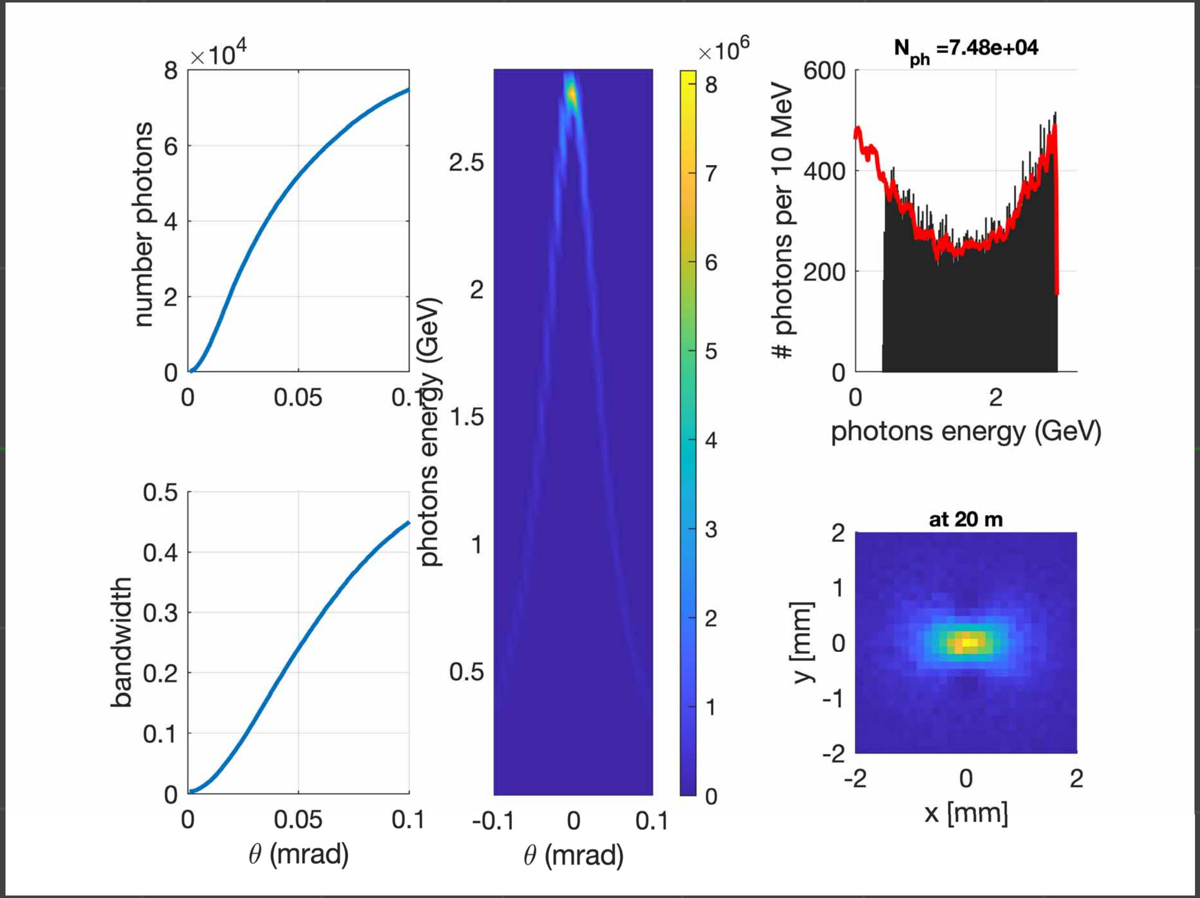

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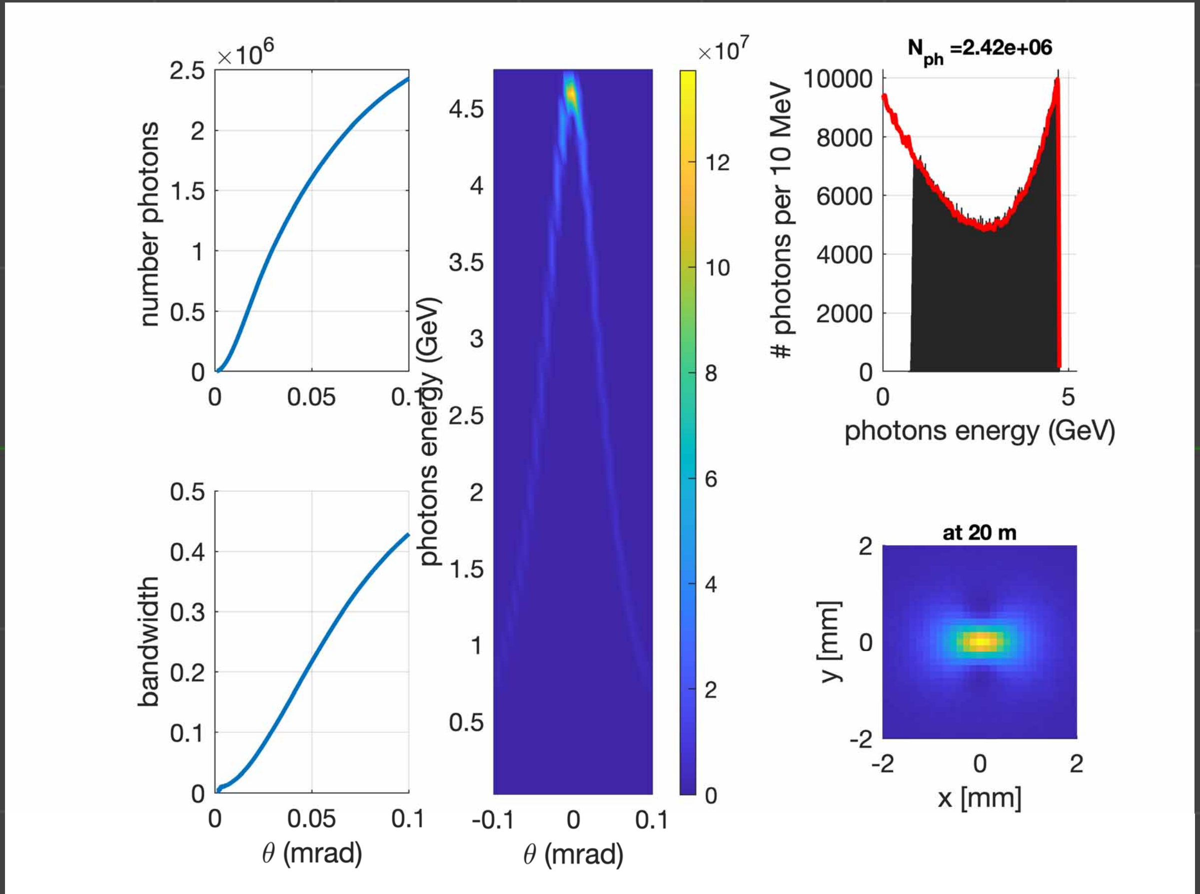

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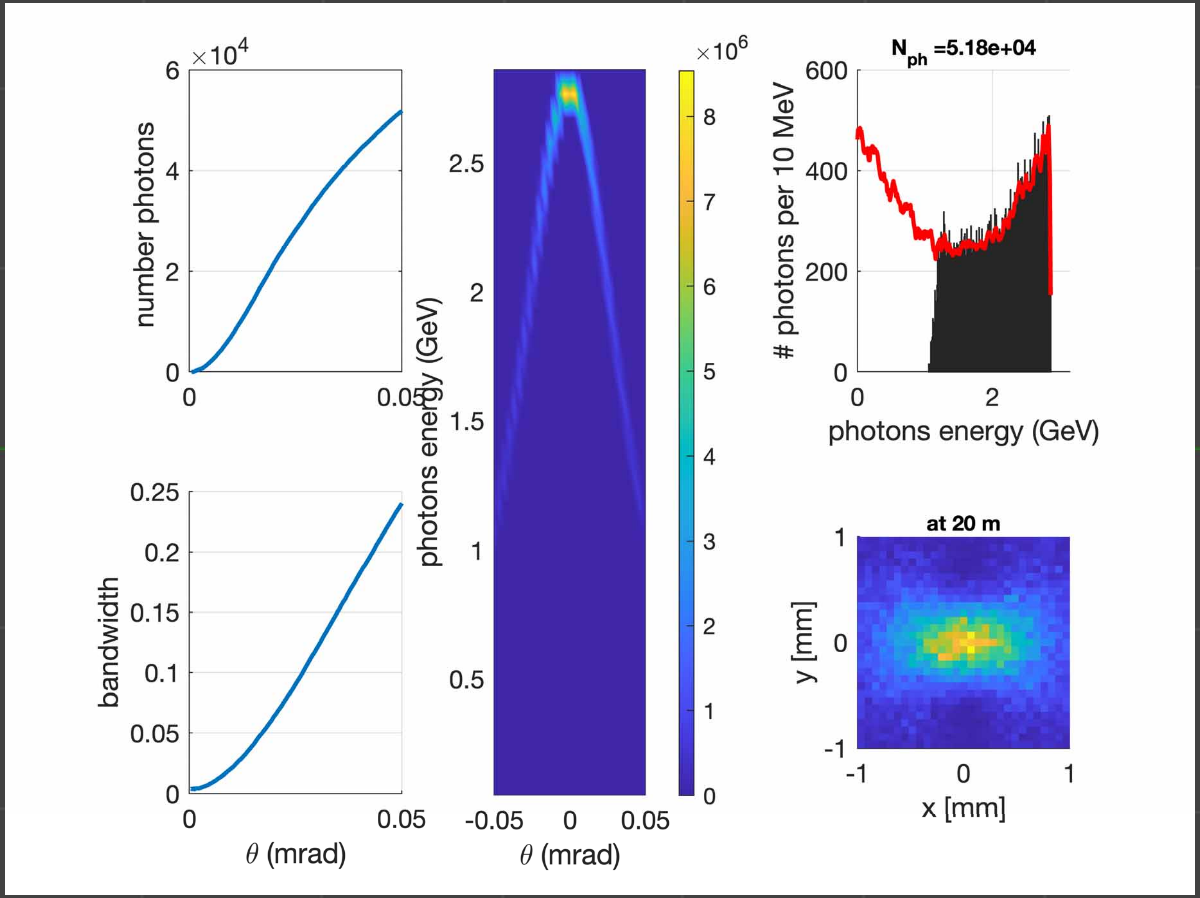

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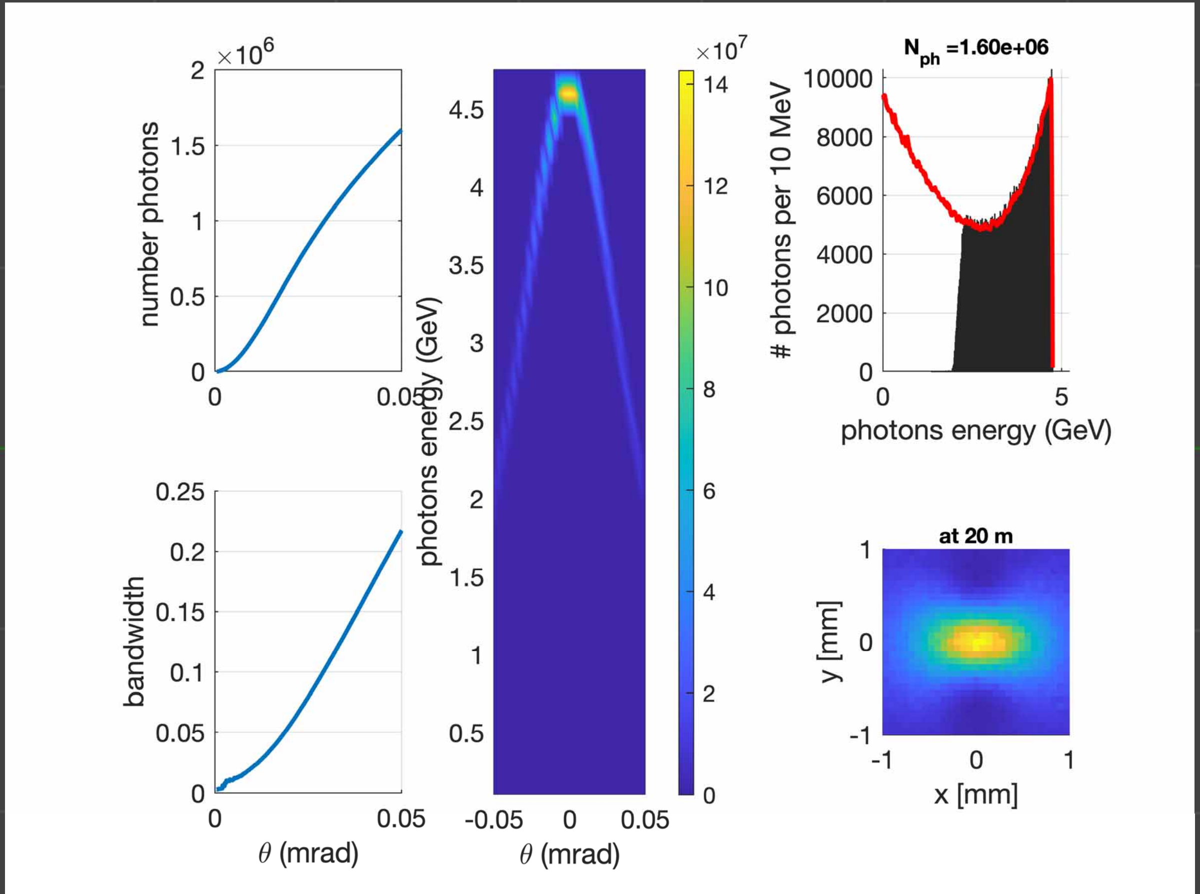

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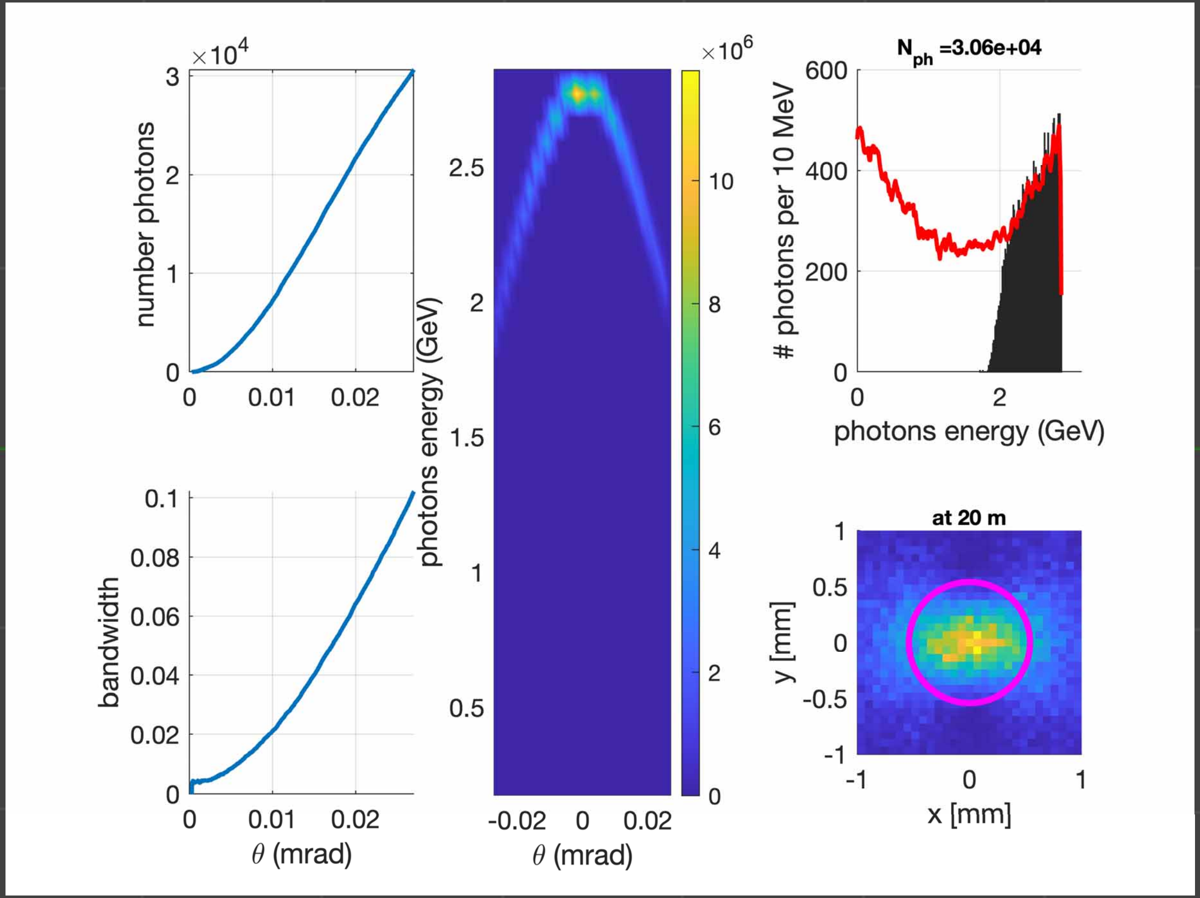

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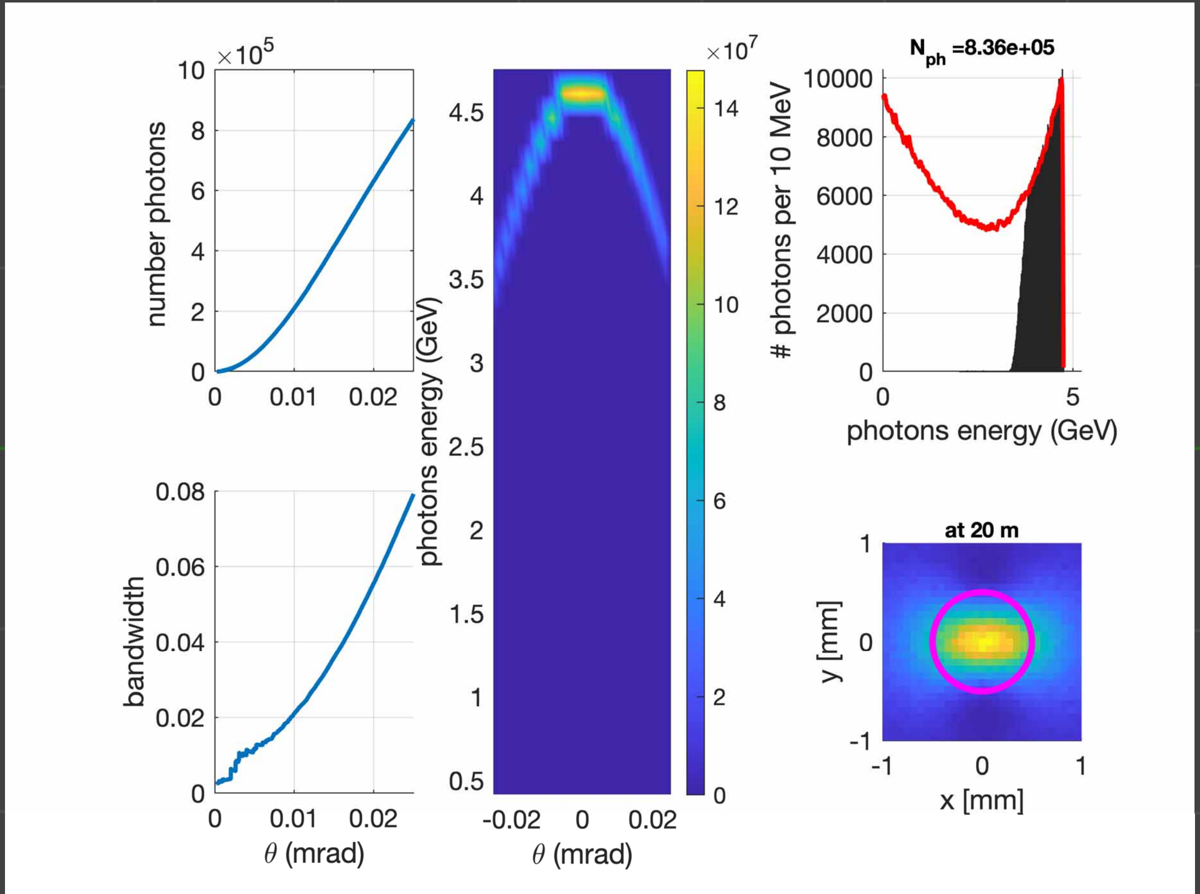

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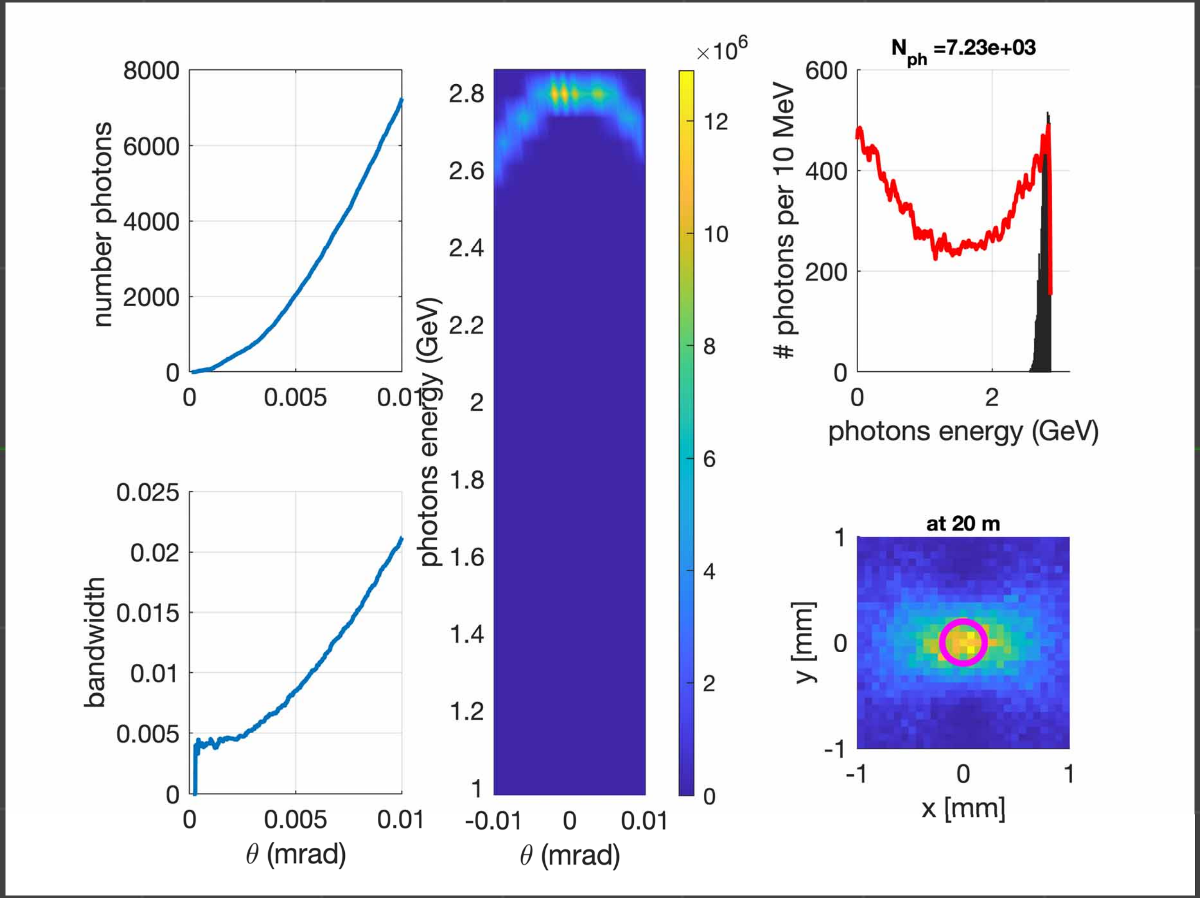

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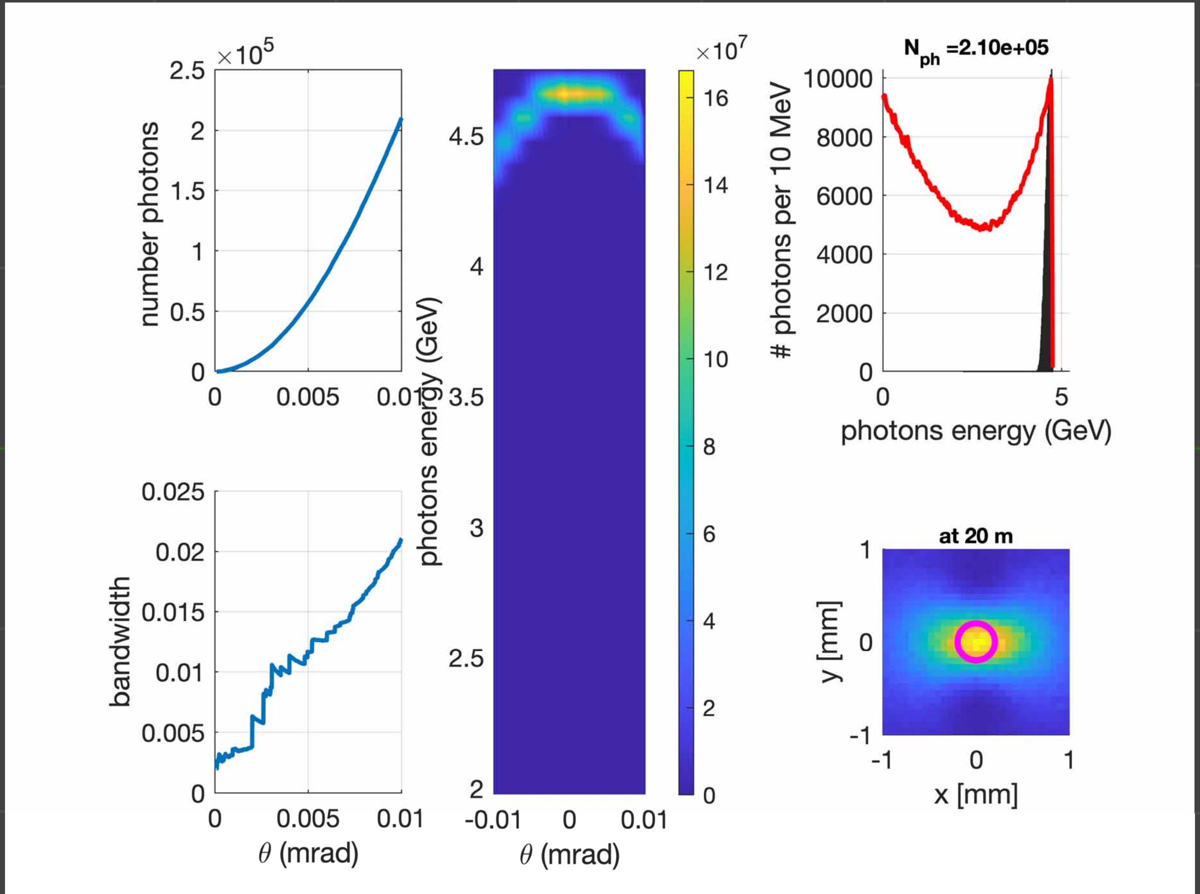

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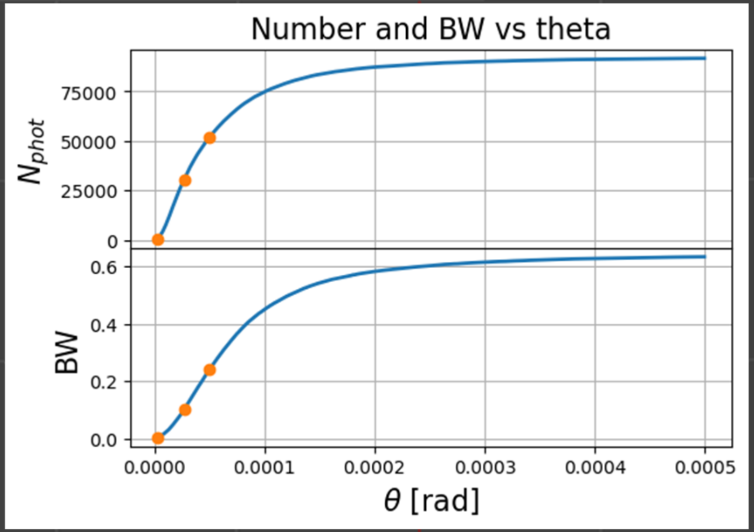
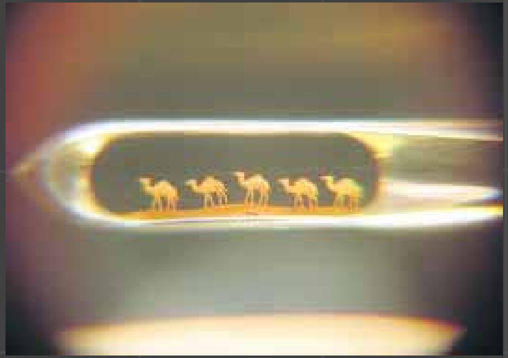
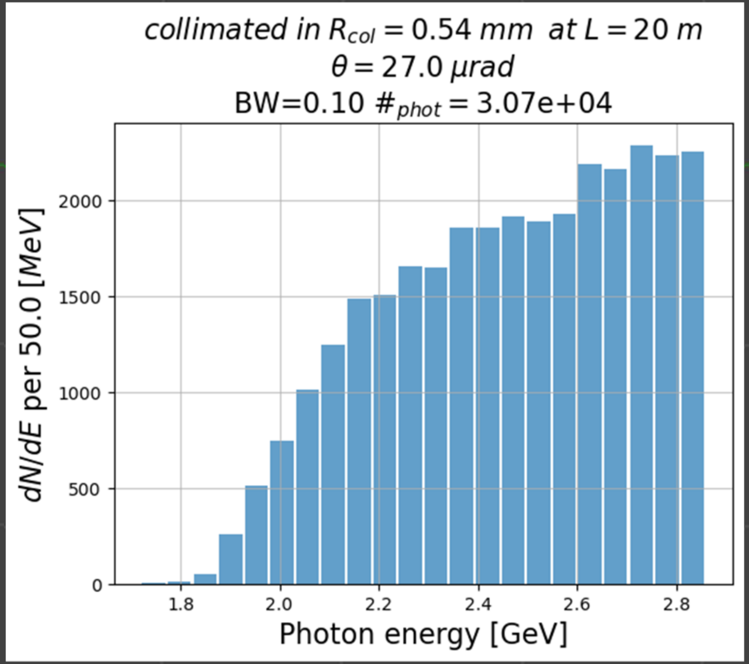
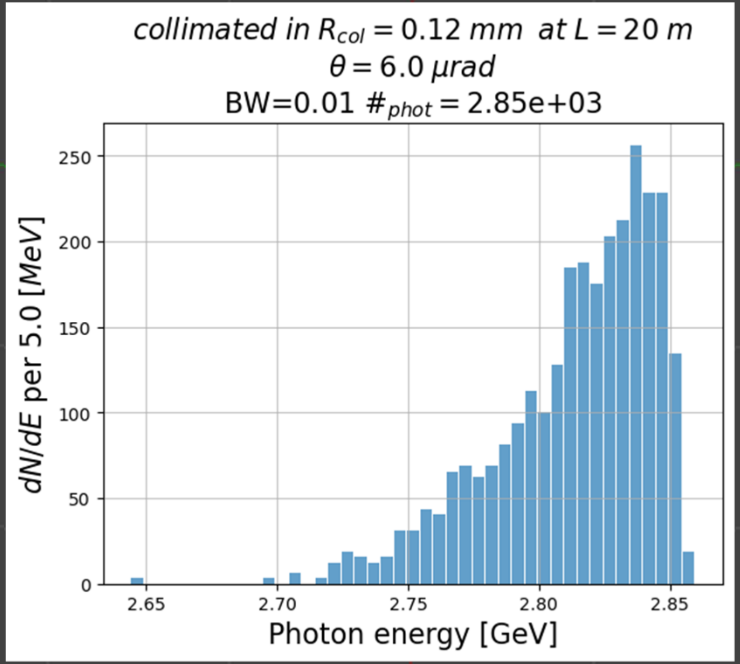
Spectrums for 1.2 eV
Rap rate 2700*10=27 kHz



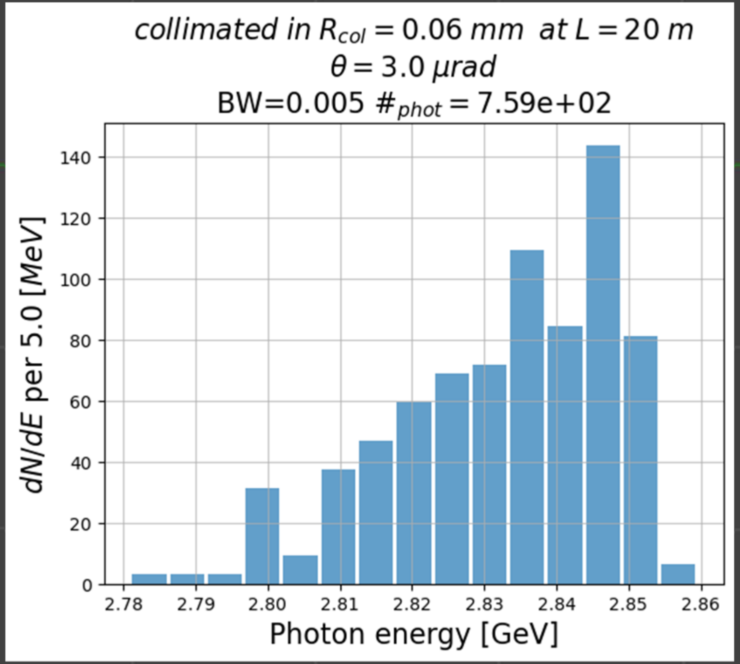




$\#_{phot}$ per sec =$8.2*10^8$

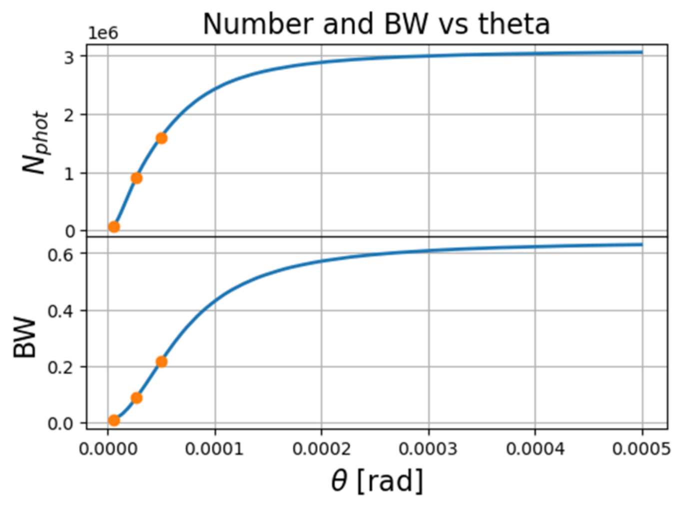


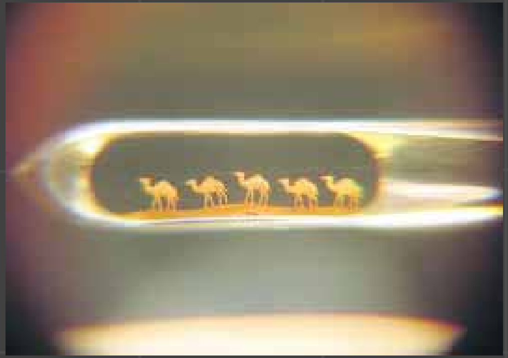
$\#_{phot}$ per sec =$7.6*10^7$

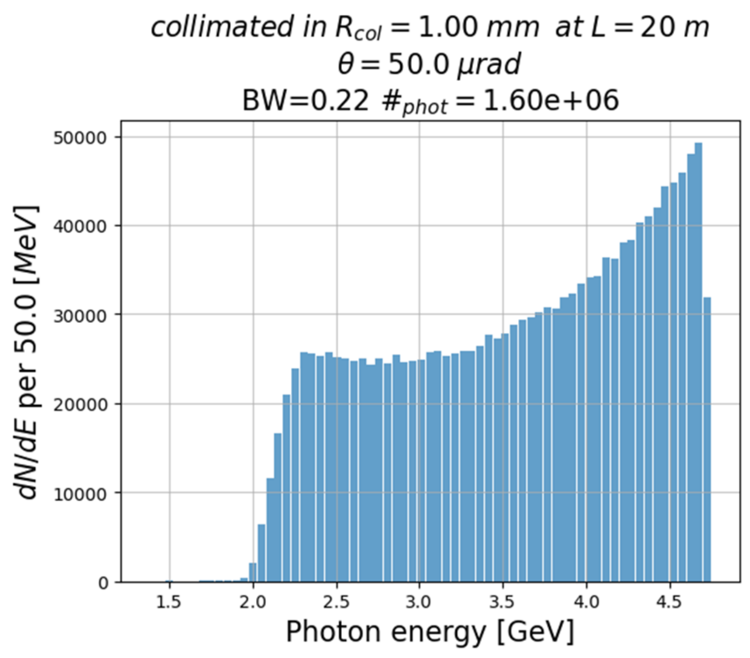


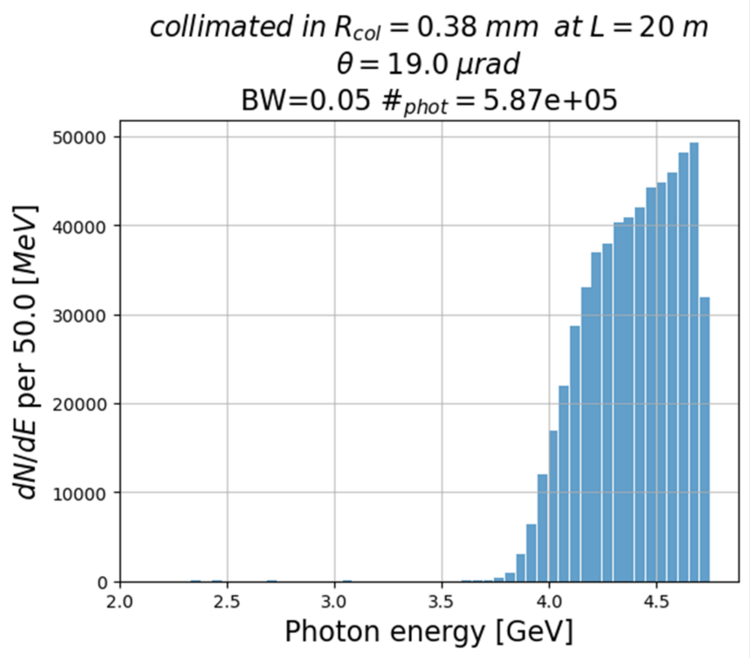
$\#_{phot}$ per sec =$2*10^7$

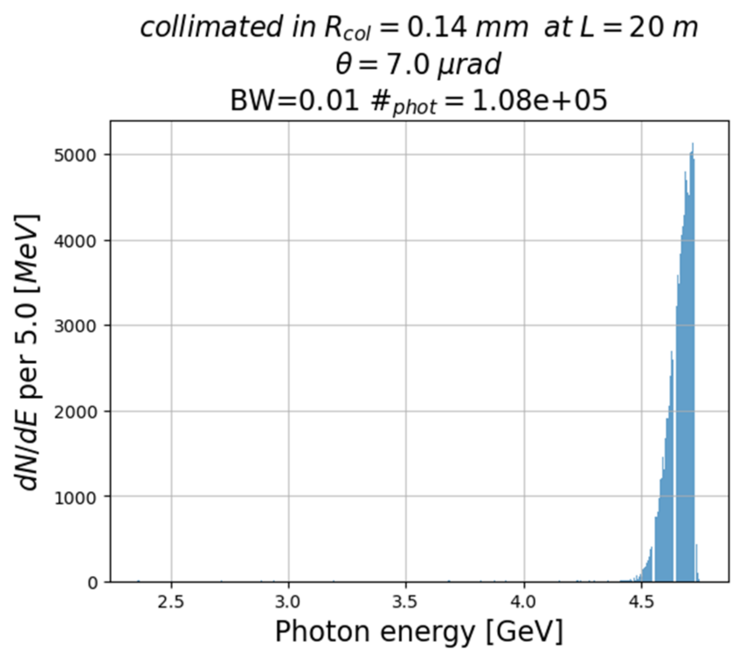
Spectrums for 2.4 eV
Rap rate 320 Hz


Number and BW vs theta




collimated in $R_{col} = 1.00\ mm$ at $L = 20\ m$
$\theta = 50.0\ \mu rad$
BW=0.22 $\#_{phot} = 1.60e+06$


collimated in $R_{col} = 0.38\ mm$ at $L = 20\ m$
$\theta = 19.0\ \mu rad$
BW=0.05 $\#_{phot} = 5.87e+05$

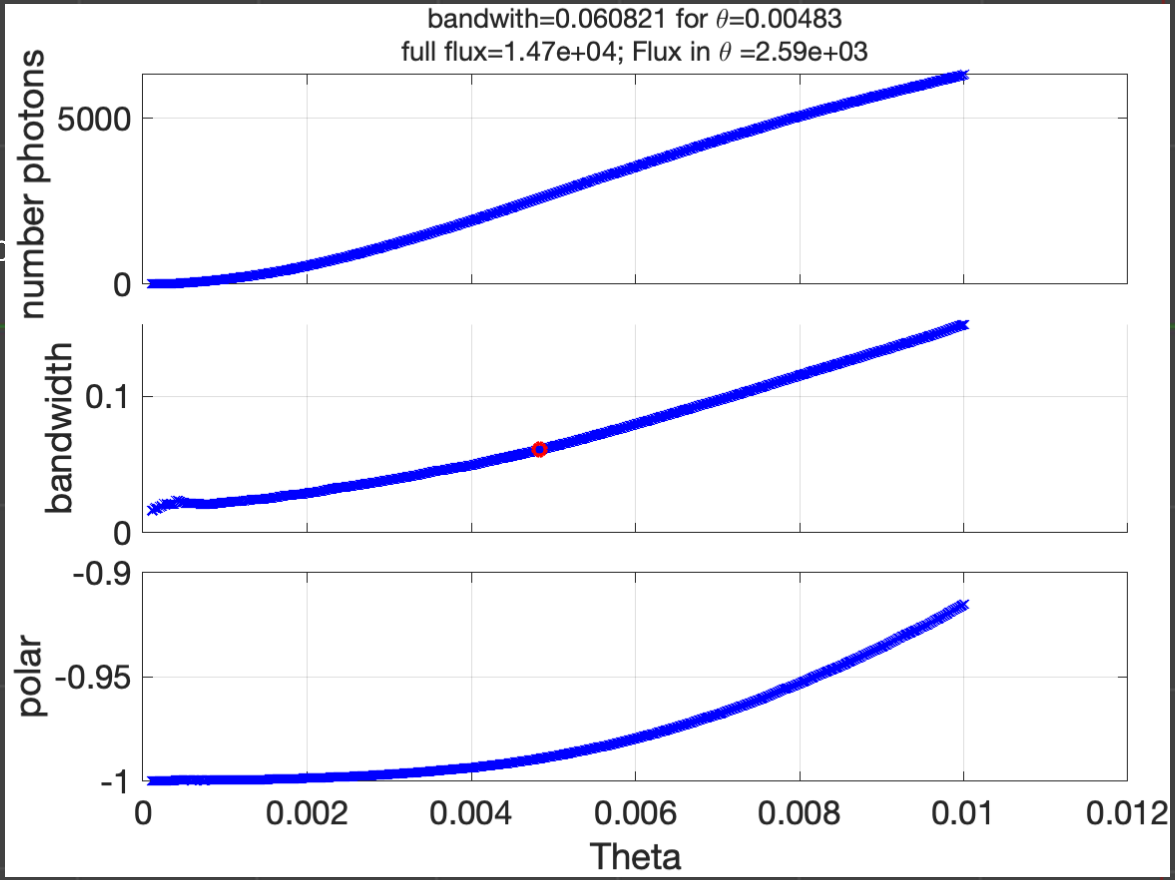

collimated in $R_{col} = 0.14\ mm$ at $L = 20\ m$
$\theta = 7.0\ \mu rad$
BW=0.01 $\#_{phot} = 1.08e+05$

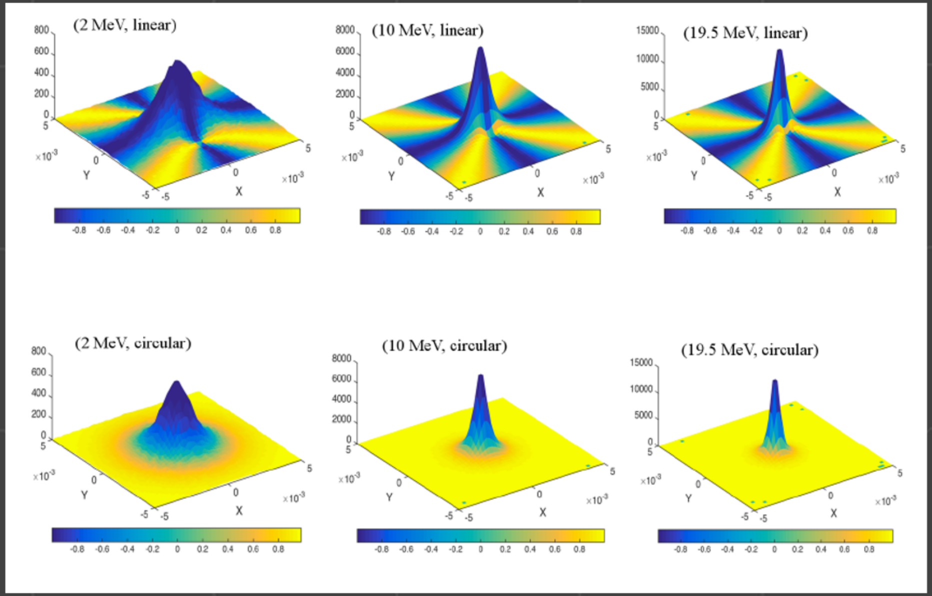
$\#_{phot}$ per sec =5.12*10^8

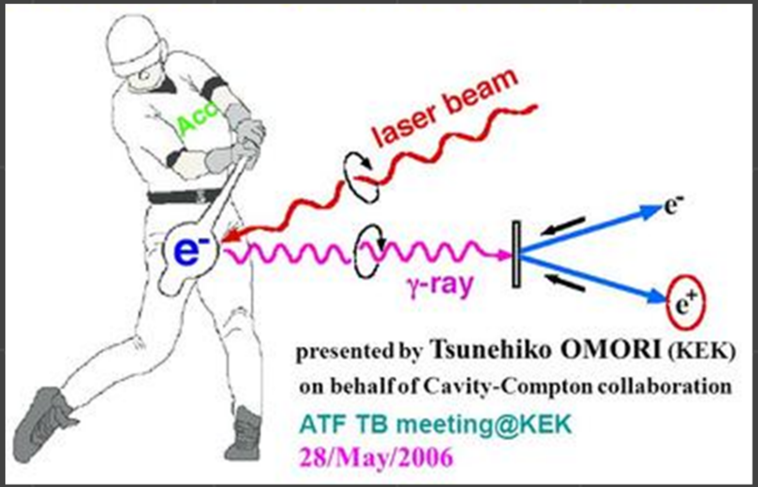
$\#_{phot}$ per sec =1.87*10^8

$\#_{phot}$ per sec =3.4*10^7

Why we so like Compton back scattering? We get X-ray with given polarization linear or circular.







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Thank you for you attention

Conclusion

Presented possibility to get source of queasy monoenergetic gamma photons
At 2.8 GeV and 4.6 GeV with low energy resolutions

First case present possibility get source compatible with Spring8 LEPS2
just installing relatively low cost laser with Fabry –Perot cavity
Instead second one give possibility reach up to 6 GeV but need a design
a new laser system to get as much as possible of rep rate of collision

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